ESTABLISHMENT OF A TORNADO DETECTION LABORATORY IN OKLAHOMA CITY, OKLAHOMA

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ESTABLISHMENT OF A TORNADO DETECTION

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PREFACE

The purpose of this thesis is to present a description of the work performed in establishing a satellite tornado detection laboratory in Oklahoma City, Oklahoma, in the Spring of 1952 and in operating and maintaining the laboratory to the present time. The scope of the material is limited to discussion of the circuitry of the equipment used and general experimental results obtained. Particular emphasis is placed on the modifications to the equipment and data taken to obtain information concerning the characteristics of the sferic waveform for periods of time up to 4000 microseconds after the sferic is initiated.

The writer wishes to express his appreciation to personnel of the Stillwater Tornado Research Laboratory for their assistance and cooperation. Particular thanks is extended to Mr. Ruben D. Kelly who constructed the sferic waveform detection equipment. The enthusiastic support of Dr. Herbert L. Jones, under whose guidance this work was performed, has been most encouraging. A word of thanks should also be given to administrative personnel of the Facilities Branch of the CAA Aeronautical Center who made the space available for the equipment installation and permitted the use of test equipment and other facilities. The cooperative attitude of the writer's wife, Helen, has been most gratifying and is deeply appreciated.

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CHAPTER I

INTRODUCTION

"Tornadoes are by far the most violent and destructive manifestations of all nature."[1] This statement is verified each year by statistical data in the number of lives lost and the millions of dollars in property damage caused by these storms. The United States Weather Bureau has released information to the effect that over the past 35 years the nation has averaged 109 tornadoes during the first six months of the year, with an average of 202 deaths. During the first four months of 1953, 249 tornadoes struck in the United States leaving over 350 persons dead and many more injured. In March, 1925, 800 persons were killed by tornadoes in Missouri, Indiana and Illinois.[2]

Oklahoma Agricultural and Mechanical College has been engaged in a research program since 1947 directed toward the establishment of an adequate warning system which could substantially reduce the loss of life caused by tornadoes. It is evident that appreciable reduction in property damage is impossible unless a means of "killing" the storm in its early stages could be devised.

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[1] William L. Donn, Meteorology with Marine Applications (New York, 1946), p. 179.

[2] "249 Twisters Hit This Year; Record Is Seen," Oklahoma City Times, June 10, 1953, p. 9.

An adequate warning system should have the following characteristics:

1. The data gathering equipment should permit continuous observation of storm activity from the early stages of development to the actual formation of a funnel.

2. The equipment should provide information from which the exact location of the storm center can be determined accurately at all times.

3. The information should be of such a nature that it is possible to definitely distinguish between at least three stages of storm development; formation of the low level thunderstorm, formation of the incipient tornado, and formation of the active tornado.

4. Interpretation of data should be accomplished as rapidly as possible and the communication system should be efficient so that the warning may be given to the citizens of the particular communities in sufficient time for them to take the necessary precautions.

The research at Oklahoma Agricultural and Mechanical College has been concerned primarily with the first three of these characteristics. The fourth logically must follow after the first three have been accomplished. At the present time, warnings are issued in Oklahoma based on prediction of tornado development from meteorological data. This system seems to offer a very accurate method of forecasting and warnings are usually issued several hours in advance. However, in most instances, the warning area is quite large. The method of identification and location of tornadoes being studied at Oklahoma Agricultural and Mechanical College is based upon observation and analysis of the electromagnetic disturbance created by and having its origin in the storm cell. The exact location of the storm is determined from continuously indicating direction finding equipment, supplemented by radar equipment when the storm is within range, approximately 150 miles. An extensive study is being made of the actual waveform of the incoming sferic in an attempt to determine as many characteristics as possible for differentiating between the three stages of storm development as related in the preceding discussion. A discussion of the equipment used in these investigations will be presented in later chapters. However it should be mentioned here that two identifying characteristics have been discovered in past studies:[3]

1. The energy spectrum of the sferic from a high-intensity thunderstorm includes frequencies higher than those normally found in the low-intensity storm.

2. The frequency of occurrence of these high-frequency sferics is materially increased as the active tornado forms.

In order to obtain complete data as to the location of the storm cell using direction finding techniques, it is necessary that observations be made from a minimum of two positions spaced some distance apart. A satallite laboratory was planned to be located in Oklahoma City, Oklahoma. Selection of this location provides a base line of approximately 60 miles in length for making triangulation calculations on storm location. The initial installation of direction finding equipment was begun in April, 1952. A statement of the purposes of the Oklahoma City laboratory includes not only the providing of additional direction finding data, but also further study of the sferic waveform to determine additional

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[3]Herbert L. Jones and Philip N. Hess, "Identification of Tornadoes by Observation of Waveform Atmospherics," Proceedings of the I.R.E., 40 (September, 1952), p. 1049.

identifying characteristics of the tornado. During the spring and summer of 1952, the direction finding equipment was placed in operation and observations were made on the movement of several thunderstorms which crossed the State during this period. A simplified waveform detector was constructed so that some indication could be obtained as to the type of signal being received. This equipment consisted of a vertical whip antenna approximately 20 feet in height feeding a 6AG7 cathode-follower stage. The signal was then fed to a conventional Class "A" video amplifier stage using a 6AC7 tube and then to a second cathode-follower output stage for driving the low-impedance coaxial transmission line. Inside the building, the signal was applied directly to a terminating resistance and the vertical amplifier of a DuMont 304-H oscilloscope. The oscilloscope was adjusted to the "driven sweep" position and the incoming sferic was utilized directly for triggering the sweep. This system, while unsatisfactory as a permanent arrangement, provided much needed experience with the nature of the problem and familiarity with the direction finding equipment. Photographic equipment was not available at this time for obtaining a permanent record of the waveforms which were observed.

Complete sferic detection and direction finding equipment was installed at the Oklahoma City laboratory in the spring of 1953. The major portion of this thesis is devoted to the investigations made and circuitry involved in the work at Oklahoma City during the spring and summer of 1953. A primary objective of the investigation during this period was to obtain more extensive data concerning the sferic waveform, with particular emphasis on its characteristics at times up to as much as 4000 microseconds after the initial surge. In the previous investigations, the oscilloscope sweep speeds which were used range from about 50 microseconds up to about 250 microseconds. This discussion will be concerned primarily with the equipment design and modifications in the circuity which were necessary to obtain the data at the longer sweep times. A detailed analysis of the waveforms will be presented in a later thesis by Mr. J. P. Lindsey.

CHAPTER II

METEOROLOGICAL CONDITIONS

Before presenting a description of the equipment and analysis of the circuitry involved in the system, it is desirable to discuss certain aspects of the meteorological conditions which are pertinent to the study of the tornado and the sferic waveforms encountered.

Formation of the Thunderstorm

All thunderstorm activity is dependent upon the existence of a meteorological situation which produces a column of rapidly rising, relatively moist air. This vertical column extends upward for several thousand feet and the air is subject to cooling as it rises. Condensation of the moisture takes place and the cumulonimbus or thundercloud is formed. If the upward velocity of the air is sufficient, the moisture will be carried to an altitude where temperatures are below the freezing point where ice and snow will form. The situation to produce the upward rush of the air may exist because of (1) pronounced local heating of the lower air layer, (2) windward slopes of steep mountains which give to the wind a vertical component of velocity, or (3) steeply sloping cold-air wedges.[1] Storms originating from the first of the above causes are quite local in nature. Very strong straight winds may be produced, but normally

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[1]William L. Donn, Meteorology with Marine Applications, p. 83.

the over-all energy levels are relatively low. The thunderstorm activity which is an almost daily occurrence in mountainous regions is a result of the second cause. These also are relatively low intensity storms. The frontal storms may be of two types, (1) underrunning and (2) overrunning. If the advance of colder air is greater at ground levels than at the higher levels, a wedge of cold air forces the warmer air upward, forming a line of clouds along the front. This is an underrunning cold front. Quite often however, the advance of colder air is more rapid at high levels than it is along the ground where frictional forces tend to retard it. This produces the overrunning cold front. The presence of this colder air above the warm air along a relatively narrow band just ahead of the front is a very unstable condition, and is in general one of the conditions contributing to the formation of the tornado. This condition is not in itself sufficient for predicting occurrence of a tornado. In the method devised by Fawbush, Miller, and Starrett, the simultaneous existence of six meteorological conditions is required before a prediction is made.[2]

Formation of the Tornado

When the overrunning cold front condition exists, the lighter warm air rushes upward with a very high vertical velocity. A towering cumulonimbus cloud is formed by this

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[2]E. J. Fawbush, R. C. Miller, and L. G. Starrett, "An Empirical Method of Forecasting Tornado Development," Bulletin of the American Meteorological Society, XXXII (January, 1951), pp. 1-9.

action. The altitude reached by the cloud is determined to a large extent by the height of the freezing line above the earth, and the violence of the storm produced increases as the vertical development of the cloud increases. This, therefore, is one reason why the thunderstorms which occur in the spring and summer are more violent than those in the winter. The maximum velocity of the rising air column occurs just behind the forward edge of the cloud formation. As the development of the storm proceeds, the vertical velocity increases and a whirling action develops in the base of the cloud surrounding the vertical air column. Further increase in vertical velocity of the air within the column results in the formation of the funnel which extends from the cloud earthward.

Accumulation of Electric Charge in the Cloud

The mechanism by which electric charge is built up in a cloud has not been definitely determined. Of all of the theories which have been advanced, two have been more favorably received than the others, those of C. T. R. Wilson and of G. C. Simpson. A general discussion of these theories is given in the following paragraphs. For specific details, any one of several good texts on the subject should be consulted.[3] For purposes of the present study, only those aspects of the theories which contribute to correlation be-

[3]C. F. Wagner and G. D. McCann, "Lightning Phenomena," Electrical Transmission and Distribution Reference Book, Westinghouse Electric and Manufacturing Co., (East Pittsburgh, Pennsylvania, 1944), Chapter 12, pp. 291 - 324.

tween the meteorological observations and the nature of the sferic waveform are of particular interest.

The theory of Wilson is premised on the existence, even in fair weather, of a large number of ions in the atmosphere and a normal electric field directed downward. The ions assumed to be present are of both positive and negative charge and have a very low velocity. When a water drop forms within a cloud, becomes larger, and begins to fall, it will become polarized through induction because of the electric field in which it exists. The direction of polarization is such that the bottom side becomes charged positively. The velocity with which the drop will fall under the influence of gravitational force is much greater than the velocity of the ions present. Negative ions will be attracted to the bottom side of the drop and the positive ions repelled. These larger drops therefore carry a negative charge toward the bottom of the cloud, leaving the upper portion with a net positive charge.

The theory of G. C. Simpson is based on the phenomenon that when water drops are broken up by a stream of air striking them, the particles of water become positively charged while the air becomes negatively charged. In the cloud, the water drops which enter the high velocity updraft are broken up and the droplets formed receive a positive charge. The upward stream of air becomes negatively charged and carries this charge away to the large body of the cloud. The small droplets recombine and fall back where they are again separated and become charged still more positively. In this way the main body of the cloud will be charged negatively with a positive charge cell located inside of the rising air column at a short distance above the base of the cloud. The distribution of positive charge in the upper portion of the cloud is explained by Simpson as being due to the motion of snow and ice particles moving at a high velocity through the air.

Regardless of which of these theories is taken as the correct one, the important factor which is common to both is that the accumulation of charge is dependent upon the column of rapidly ascending air. The rate of build up of the charge will be more rapid for higher air velocities within this column. Using either theory, a satisfactory explanation for the increase in discharge occurrence rate which has been observed in tornadoes will result.

Mechanism of the Lightning Stroke

Electric charge will continue to accumulate within the cloud until the potential gradient reaches the breakdown value. This value is normally on the order of 1,000,000 volts per meter at normal air density in the presence of large cloud droplets.[4] When this critical potential has been reached the discharge process begins. For a single stroke from cloud to ground the process may be divided into three stages, (1) the pilot streamer, (2) the stepped leader, and

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[4]L. P. Harrison, Lightning Discharges to Aircraft and Associated Meteorological Conditions, National Advisory Committee for Aeronautics Technical Note No. 1001, (Washington, 1946), p. 134.

(3) the return stroke.

Initially, a stream of electrons called a pilot streamer extends into the surrounding air from the cloud toward the earth. It will continue to advance as long as the potential gradients encountered continue to be sufficiently large, leaving behind it a narrow ionized path. Since the progress of the streamer is determined by the potential gradient at its tip end, it may proceed in more than one direction from several points along its path of descent, giving it a forked characteristic. Since the current carried by this streamer is relatively small, of the order of one ampere or less, it is doubtful that this stage of development of the stroke contributes appreciably to the sferic waveform normally received. The velocity of propagation of the pilot streamer is between 62 and 1240 miles per second.[5]

The stepped leader begins its descent after the pilot streamer has extended but a relatively short distance and in general follows along the path which has been ionized. Since it travels at a much higher velocity, it overtakes the pilot streamer and when it has done so pauses for a period of several microseconds. During this pause, the pilot streamer advances farther. At the end of the pause, another leader starts downward from the cloud, following the same path, and again overtakes the pilot streamer where it pauses once more. This process is repeated many times until the leader tip is

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[5] *Ibid.*, pp. 137-138.

quite near the earth. As the leader approaches the earth the positive charge density on the earth's surface increases and eventually the potential gradient will be sufficient for a positive leader to begin to extend upward. When the tips of these two leaders meet, a tremendous surge of positive charge occurs, moving from the earth to the cloud along the low resistance, ionized path which has been prepared by the stepped leader. It is very doubtful that the stepped leader contributes appreciably to the sferic waveform since the current involved is still relatively low. The velocity of propagation of the stepped leader is of the order of 31,000 miles per second, however, due to the pauses and the fact that after each pause it is initiated again from the cloud, its rate of progress from cloud to earth is the same as that of the pilot streamer.[6]

The return stroke which carries positive charges from the earth to the cloud is the most intense portion of the lightning discharge. The current carried may reach values as great as 150,000 amperes or more, with average currents of the order of 25,000 amperes. The velocity of propagation is between 12,400 miles per second to 87,000 miles per second. The initial current surge lasts for from 10 to 100 microseconds and is followed by a relatively low current of from 1000 to 100 amperes, lasting for a period of from one millisecond to as long as one tenth of a second. This return

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[6] _Ibid._, pp. 137-139.

stroke is the major contributor to the sferic waveform.[7]

In many cases, a second discharge or more may occur over the same path. These are probably due to other charge centers in the cloud which contain insufficient charge to form an initial pilot streamer, but after the original low resistance path is prepared, the potential gradient becomes sufficient for discharge to take place. The return stroke in these cases is usually preceded by a dart leader, so called because it does not proceed in steps and is not as forked as the stepped leader. Currents in these multiple strokes may even exceed that in the initial return stroke, hence they will contribue appreciably to the sferic waveform observed.[8]

Conclusions

The study of meteorological conditions producing thunderstorm activity and the nature of the lightning discharge itself has yielded an explanation as to why the rate of discharge will increase greatly during tornadoes. This is based upon the increase in rate of charge accumulation in the cloud due to the very high vertical velocity of the air in the upward rushing column.

The presence of the higher frequency components in the sferic waveforms during tornado activity cannot be definitely accounted for on the basis of the meteorological conditions

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[7]*Ibid.*, pp. 139 - 141.

[8]*Ibid.*, pp. 141 - 142.

discussed in this chapter. Dr. K. B. McEachron of the General Electric Company has postulated that these components may be produced by a static generator action of the whirl.[9] Other theories which might be considered include the possible variations in the resonant characteristics of the cloud itself acting as a capacitive electrical element and the discharge path having inductive qualities. It is known that the effective resistance of a gaseous discharge path varies in a complex manner with time, exhibiting negative resistance characteristics over certain periods.[10] All of these possibilities should be given further study if a satisfactory explanation is desired in the future. One important fact which must be kept in mind is that the actual sferic wave shape is not the shape of the actual current flow in the discharge, but is proportional to the derivative of the current flow with respect to time. Thus for a simple discharge where the current rises to a maximum value then decreases again to zero, the sferic wave shape polarity would go through a complete reversal from positive to negative or vice versa depending upon the initial starting direction of current flow.

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[9]Herbert L. Jones, A Sferic Method of Tornado Tracking and Identification, Oklahoma Engineering Experiment Station Publication No. 82, Oklahoma Agricultural and Mechanical College, Stillwater, Oklahoma, (January, 1952), p. 9.

[10]W. J. Kessler, Direction Finding and Ranging on Atmospherics, Engineering and Industrial Experiment Station, University of Florida, Gainsville, Florida, (Sept., 1948) pp. 42 - 44.

CHAPTER III

INSTALLATION AND CIRCUITRY OF EQUIPMENT

The Tornado Research Laboratory in Oklahoma City, Oklahoma is loacted at the Municipal Airport, Will Rogers Field. The site is on the west side of the airport, at the north edge of the area occupied by the Civil Aeronautics Administration's Aeronautical Center. The selection of this site was based primarily on the fact that it would be easily accessible to personnel in case of storm development during their normal working hours. Another advantage considered was the availability of electric power and telephone service. The primary disadvantage of the site was the proximity of other electrical and electronic equipment. A filter was necessary to eliminate interference from a nearby low frequency radio range station.

The equipment as initially installed was constructed by personnel of the Tornado Research Laboratory at Stillwater, Oklahoma. Since detailed discussions of most of the circuits may be found in other publications, only a general discussion is included here. In order to obtain data concerning the characteristics of the sferic waveforms for periods up to 4000 microseconds in duration, several modifications of the original equipment were necessary. These modifications are discussed in greater detail. Other differences from equipment previously used are mentioned in the general discussion.

Direction Finding Equipment

The direction finding equipment was designed and constructed by Vernon D. Wade.[1] A block diagram of this equipment is given in Figure 1. Details of construction and circuit analysis may be found in theses by Wade and Holzberlein.[2] The antenna system consists of two separate loops, one oriented with its plane in a North-South direction and the other with its plane in an East-West direction. Signals from each of these loops are amplified by separate and identical amplifiers. The output of the North-South amplifier is used to drive the vertical deflection plates of a 2AP1 cathode-ray tube and the output of the East-West amplifier drives the horizontal deflection plates of the same cathode-ray tube. Since the voltage induced in each of the loops by a vertically polarized wave front moving across it is dependent upon the angle of incidence with the loop, a line will be produced on the cathode-ray tube which indicates the direction from which the signal arrives at the array. Sense circuits have not been incorporated in the direction finder, hence a 180° ambiguity exists in the indication. This is not particularly disadvantageous since the location of the squall line is generally known and in addition ambiguity will be eliminated when triangulation with the

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[1]Vernon D. Wade, <u>Development and Operation of a Crossed Loop Sferic Direction Finder</u>, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1951.

[2]Thomas Milton Holzberlein, A Study of Tornado Tracking Equipment, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1951.

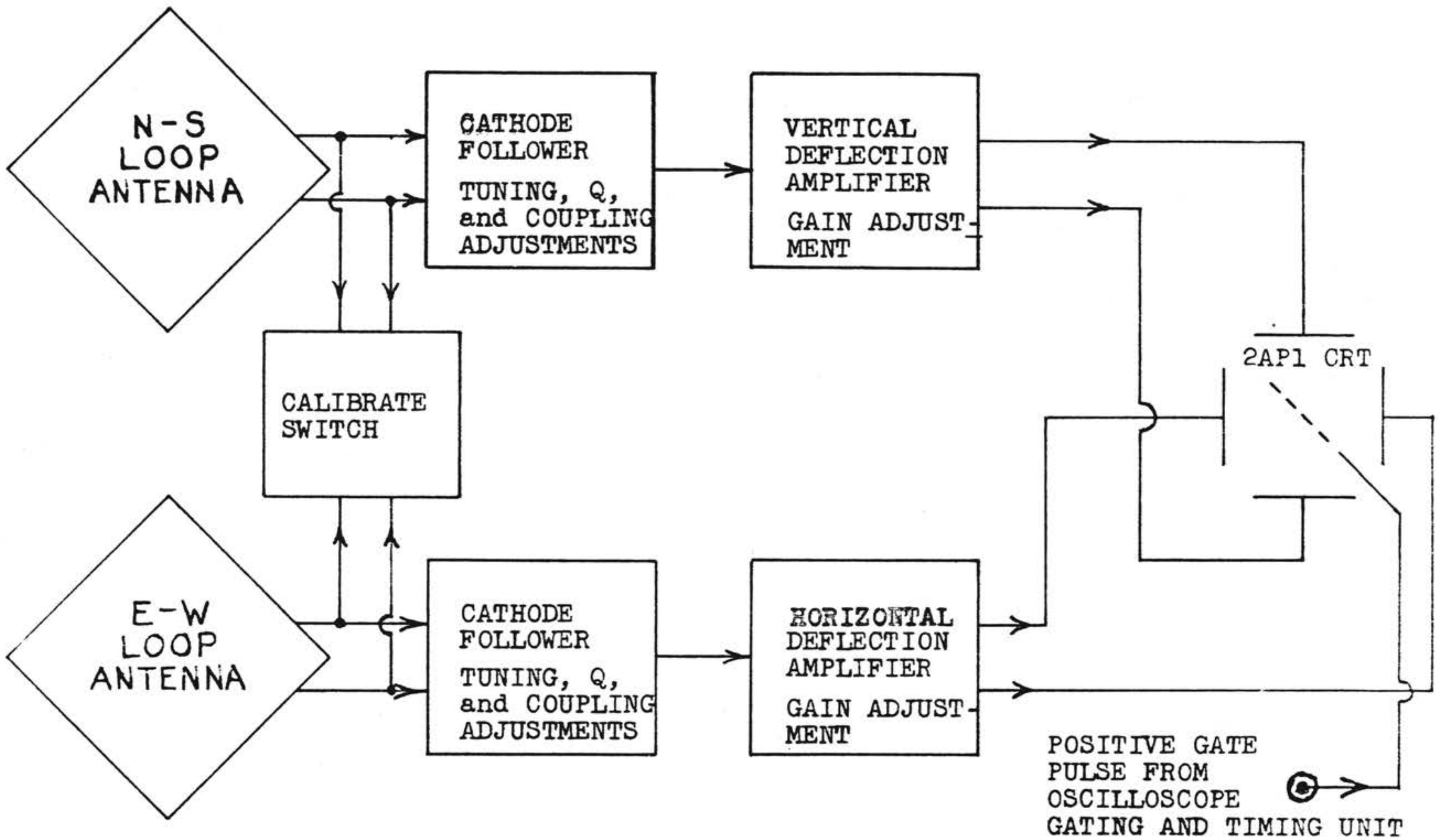

FIGURE 1. DIRECTION FINDING UNIT, BLOCK DIAGRAM

Stillwater laboratory is accomplished. A gating pulse is obtained from the sferic waveform detection equipment to intensify the cathode-ray tube simultaneously with the trace on the wave shape scope. The only modification which was made to this equipment was to replace the three-conductor cable from the antennas to the amplifiers and associated connectors. This was done to obtain longer cables so that the antennas could be located an appreciable distance from the surrounding buildings.

Sferic Wave-Shape Equipment

The sferic wave-shape equipment was constructed by Mr. Ruben D. Kelly of the Stillwater Tornado Research Laboratory. Initially, the maximum duration of the oscilloscope sweep was limited to approximately 400 microseconds. Since one objective to be accomplished at the Oklahoma City Laboratory was to obtain data concerning the wave shape of the sferics at sweep durations of up to 4000 microseconds, it was necessary to make modifications in the equipment to provide for this longer duration with satisfactory timing markers. These modifications are discussed in detail in the following sections. The entire wave-shape equipment is divided into smaller units for purposes of discussion. A block diagram of the equipment is shown in Figure 2.

Signal Amplifier Circuits

A schematic diagram of the complete system of signal amplification is given in Figure 3.

A vertical whip antenna approximately 6.5 feet in

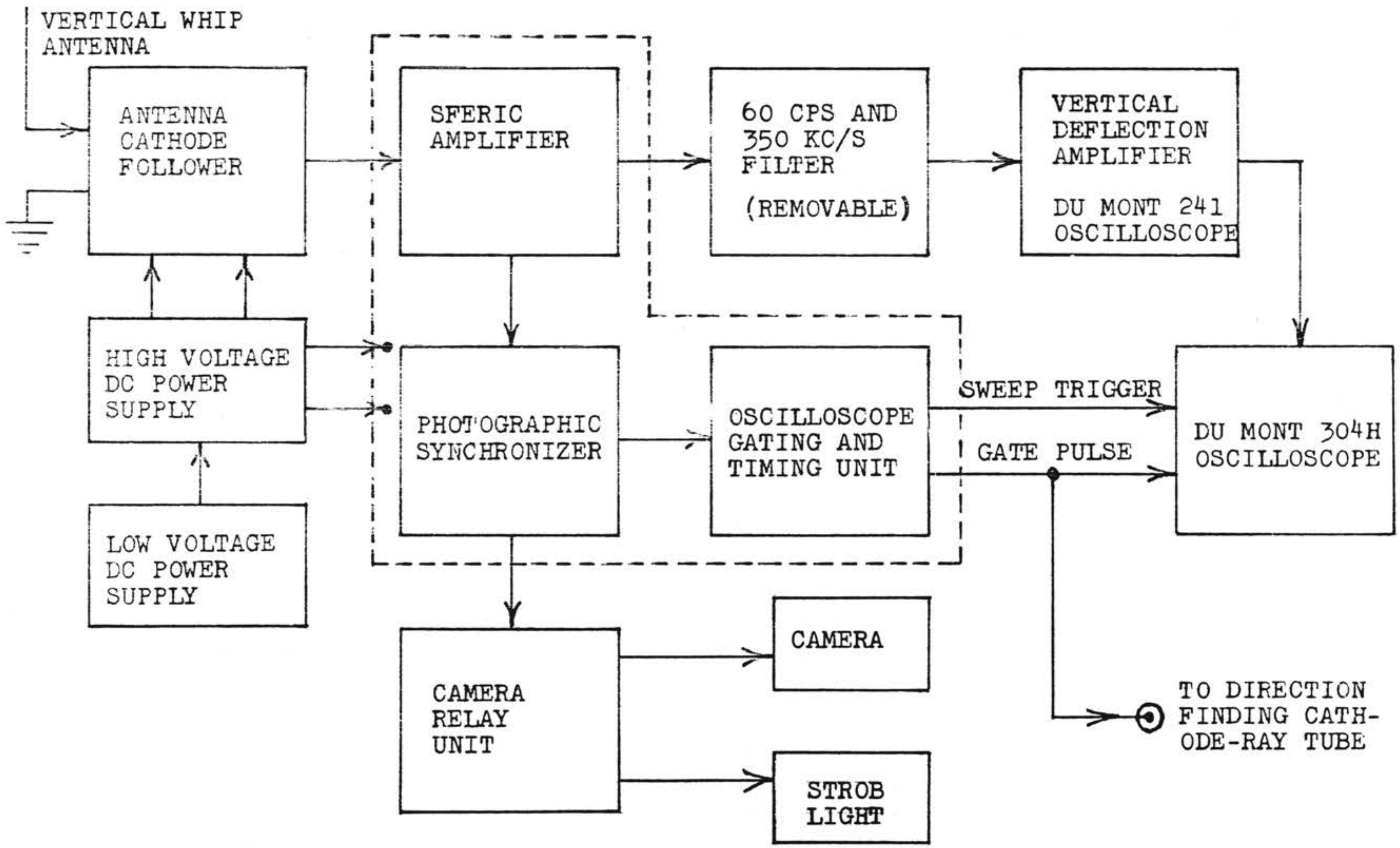

FIGURE 2. SFERIC WAVEFORM DETECTOR, BLOCK DIAGRAM

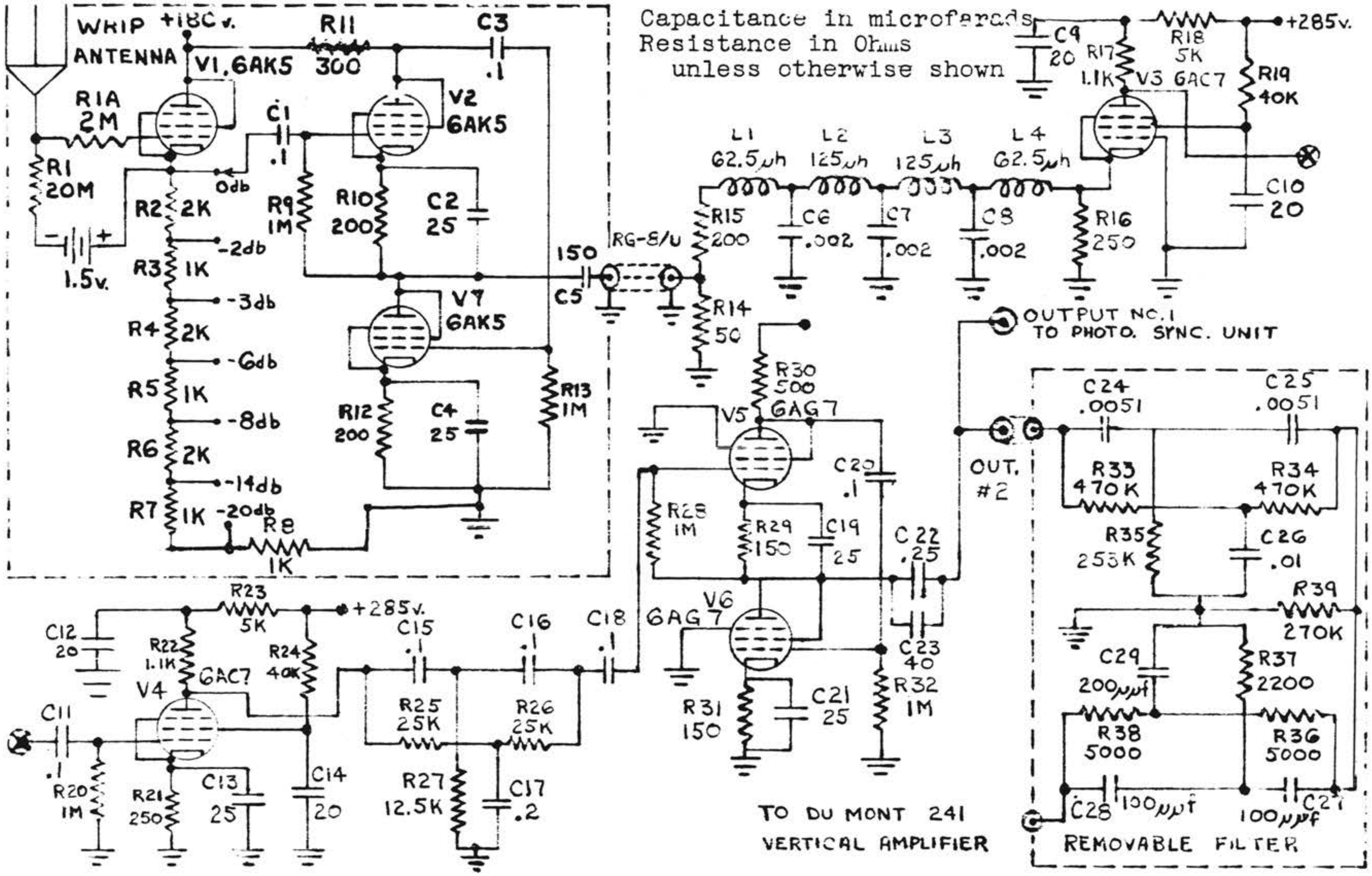

FIGURE 3. SFERIC AMPLIFIER SYSTEM, SCHEMATIC DIAGRAM

length is connected through a 2 megohm resistor to the grid of a 6AK5 cathode follower stage having a step resistance attenuator in the cathode circuit. This attenuator is necessary in order to prevent overdriving the following stages during periods of high-intensity activity. It was necessary to add the 2 megohm resistor, R1A, in series with the grid of V1 to prevent "grid leak" detection of a very strong signal from nearby broadcast station KOMA. A second cathode follower stage is used to reduce the loading on the input stage and to provide a low impedance output for driving the RG-8/U transmission line.[3,4] All voltages for operation of these amplifiers are supplied from electronic power supplies located in the equipment room and are fed to the unit through separate shielded cables. All other circuits are located in the equipment room.

A 50 ohm resistance, R14, properly terminates the transmission line at the receiving end. A low pass filter having a cut-off frequency of 600 kilocycles per second is incorporated between this terminating resistance and the next amplifier stage. This is done to eliminate broadcast station interference. Terminating resistance, R16, is also the

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[3]Herbert L. Jones, Research on Tornado Identification, Second Quarterly Progress Report, File Number 11587-PH-91, Signal Corps Research, pp. 7 - 10.

[4]Albert Charles Odell, A Study of Tornado Research Equipment, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1953, pp. 5 - 8.

cathode resistor for V3, a 6AC7 grounded grid amplifier[5] V4 is a conventional pentode amplifier using a 6AC7 tube with a low plate load resistance to maintain the response at high frequencies. The output of this stage is coupled to a two tube cathode follower through a parallel-T filter designed for a rejection frequency of 60 cps. Two 6AG7 tubes are used in the cathode follower in an arrangement similar to that employed in the second cathode follower stage of the antenna amplifier unit.[6] Two outputs are obtained from this stage. One provides a signal for the photographic synchronizer unit, which is the first unit used for developing control signals for camera operation, triggering the oscilloscope sweep, unblanking of the oscilloscope, etc. The other output, the signal output, is fed to a two section, parallel-T filter network. This filter is placed in the system only during periods of low level activity when it is necessary to operate the amplifier at very high gain. The first section is a parallel-T having a rejection frequency of 60 cps and the second section is a parallel-T having a rejection frequency of approximately 350 kilocycles per second to eliminate interference from a nearby low frequency radio range station. To obtain a better frequency response, this filter unit is removed when high frequency components are likely to be found in the incoming sferic. Generally,

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[5]Herbert L. Jones, Research on Tornado Identification, Fifth Quarterly Progress Report, File Number 11587-PH-91, Signal Corps Research, pp. 10-13.

[6]Calvin M. Hammack, "Cathode Follower of Very Low Output Resistance," Electronics, (November, 1946), pp. 206-210.

the sferic signal level during these periods is sufficiently large to allow the amplifier to be operated with a gain low enough that the interfering signals are too small to cause any appreciable distortion of the sferic waveform. Overall frequency response curves of the complete system with the filter unit inserted and with it removed are shown in Figure 4. Following the filter unit, the signal is fed to the vertical amplifier of a DuMont 241 oscilloscope.[7] This amplifier has a much better frequency response than that vertical amplifier in the DuMont 304-H oscilloscope. It is essentially flat from 20 cps to 1 megacycle per second, while the DuMont 304-H amplifier response is down to 50% at a frequency of 300 kilocycles per second.[8] However, the 304-H was the only oscilloscope available having a driven sweep synchroscope feature, hence is used for displaying the wave shape. The final amplifier stage of the DuMont 241 scope consists of two 6AG7 tubes connected in push-pull. Signals are taken from each of the plates and fed through separate coaxial cables directly to the vertical deflection plates of the DuMont 304-H scope. An additional advantage obtained by using the separate amplifier is that the gain may be changed without opening the light box.

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[7] Operating and Maintenance Manual, DuMont Cathode-Ray Oscillograph Type 241, Instrument Division, Allen B. DuMont Laboratories, Inc., Clifton, New Jersey.

[8] Operating and Maintenance Manual, DuMont Cathode-Ray Oscillograph Types 304-H and 304, Instrument Division, Allen B. DuMont Laboratories, Inc., Clifton, New Jersey.

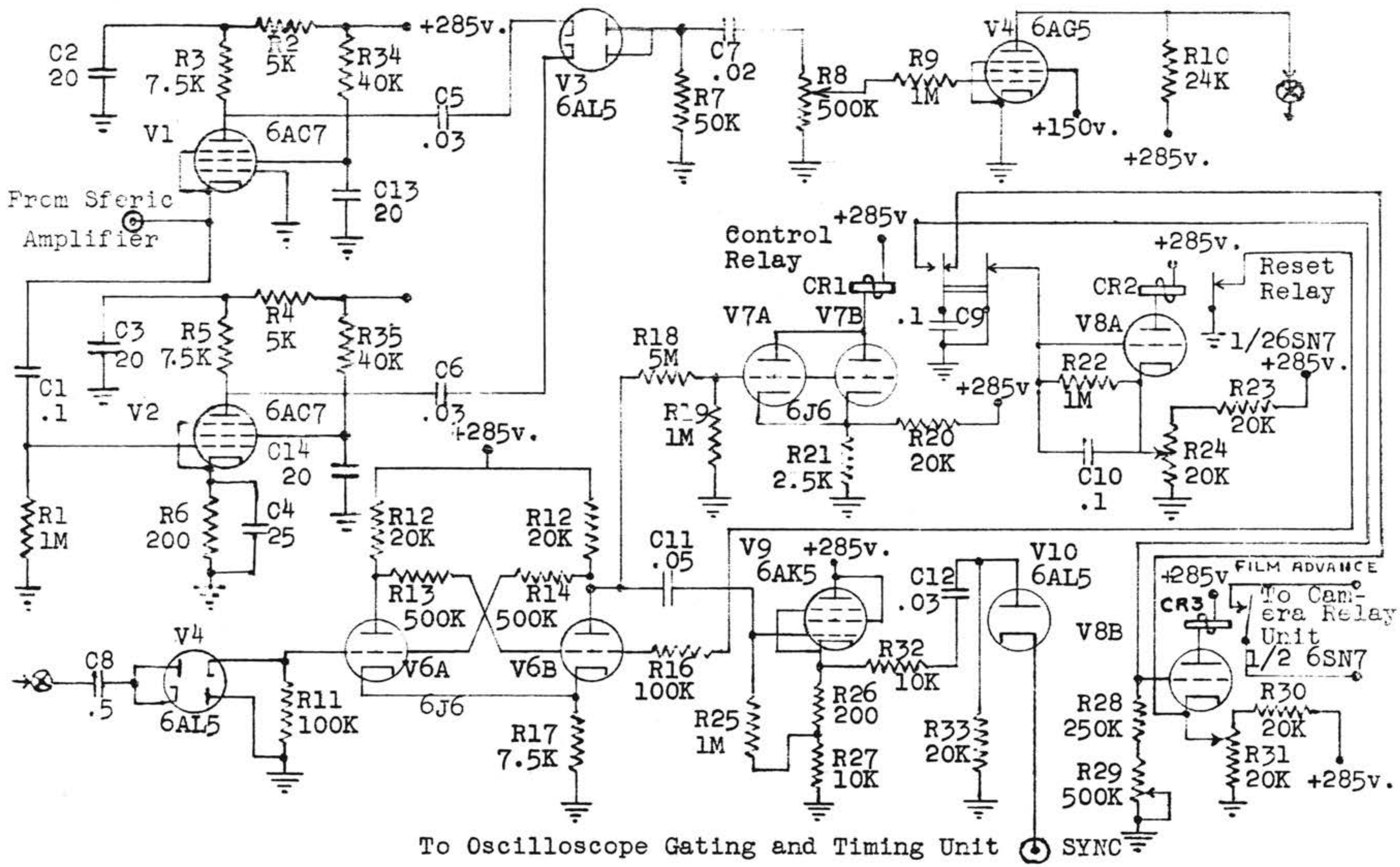

FIGURE 4. PHOTOGRAPHIC SYNCHRONIZER UNIT, SCHEMATIC DIAGRAM

Photographic Synchronizer[9]

The purpose of the photographic synchronizer is to provide control signals for simultaneous operation of the camera relay unit and the oscilloscope gating and sweep trigger unit. Driving signal for this unit is obtained from the signal amplifier as indicated on the schematic diagram, Figure 5. The initial impulse of the sferic may be of either positive or negative polarity. It is necessary that the control signals be generated by the leading edge this first impulse. The signal is fed simultaneously to the cathode of a 6AC7 grounded-grid amplifier, V1, and to the grid of a 6AC7 grounded-cathode amplifier, V2. The plates of these tubes are connected to a dual diode 6AL5, one to the cathode of each half. With the two plates of this tube, V3, tied together, a negative voltage will be produced across the load resistor, R7, for incoming sferics of either positive or negative polarity. A portion of this voltage, as determined by the adjustment of the sensitivity control, R8, is applied to the grid of a 6AG5 amplifier, V4. Coupling to the following stage, an Eccles-Jordan trigger circuit, is through a 6AL5 diode connected so as to insure that only positive going voltages will be present across R11. The Eccles-Jordan circuit provides the primary control voltage for all functions mentioned above.

In the initial quiescent condition, the second tube of

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[9]Jones, Research on Tornado Identification, Second Quarterly Progress Report, pp. 10 - 13.

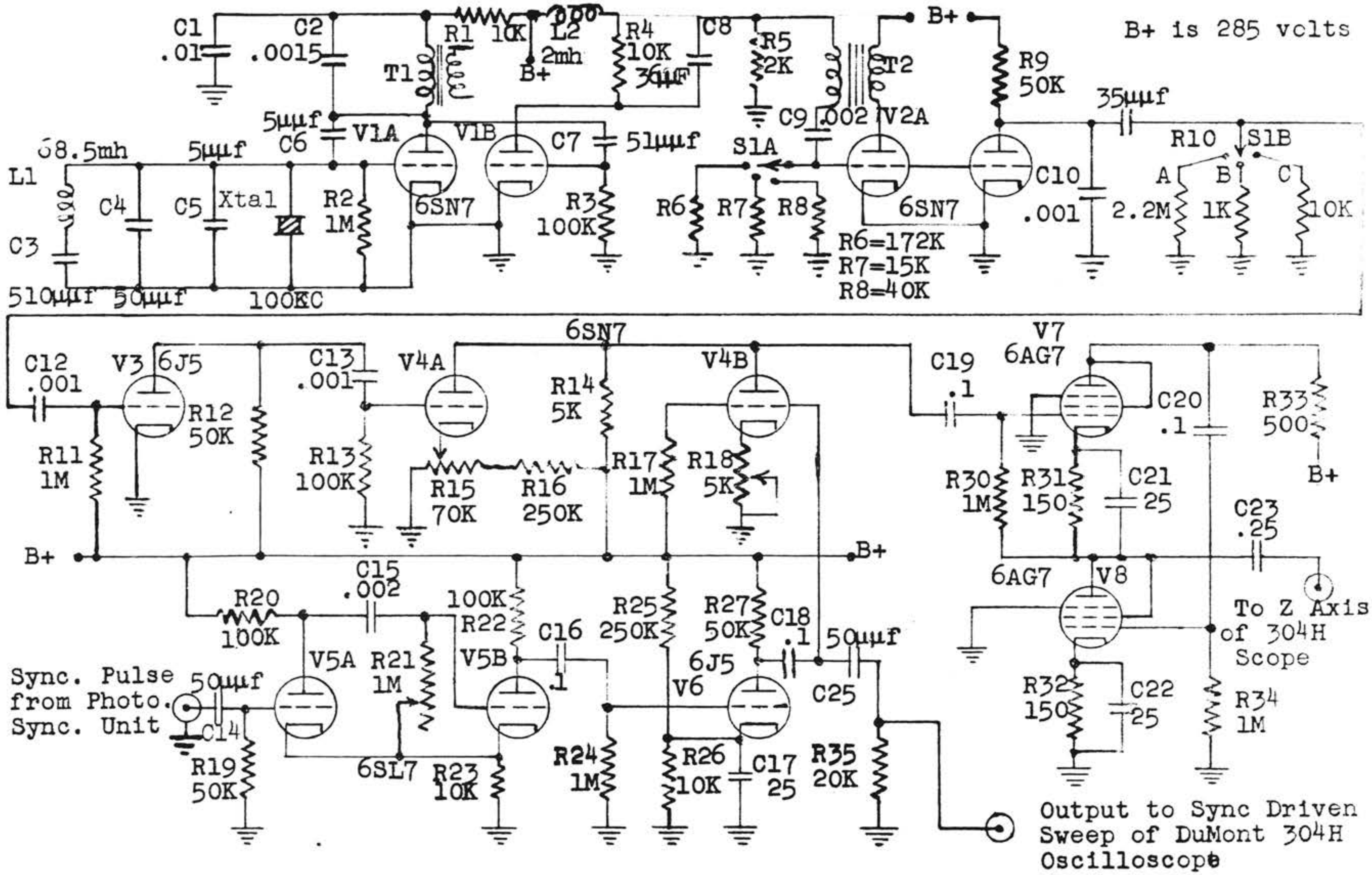

FIGURE 5. OSCILLOSCOPE GATING AND TIMING UNIT, SCHEMATIC DIAGRAM

the Eccles-Jordan trigger circuit, V6B, is conducting. The first tube, V6A, is cut off. Application of a positive voltage of sufficient magnitude to the grid of V6A will cause this tube to conduct and cut V6B off. The circuit will remain in this second stable condition until the reset relay, CR2, is energized, removing the ground from the grid circuit of V6B. When V6B is not conducting, its plate voltage is equal to the plate supply voltage. This increase of potential is applied to the grids of the two halves of a 6J6 tube, V7A and V7B, connected in parallel. These tubes in parallel can safely carry sufficient current to operate control relay CR1 when the grid voltage is increased. Fixed cathode bias is provided for this stage by a voltage divider between the plate supply voltage and ground, R20 and R21.

The control relay, CR1, controls the operation of two other relay circuits, the reset relay, CR2, and the film-advance relay, CR3. As mentioned previously, the reset relay removes the ground from the grid circuit of the second tube of the Eccles-Jordan trigger circuit to return it to its initial condition in readiness for the next sferic. To prevent overloading of the camera circuits and give the camera sufficient time to perform satisfactorily, this relay circuit provides for adjustment of the reset time of the trigger circuit. Capacitor, C10, is initially charged to a voltage as determined by adjustment of the reset time potentiometer, R24. The cathode voltage of V8A is sufficiently positive to hold the tube cut off. When the ground is removed from the grid by the action of the control relay, the capacitor begins to discharge through R22, a 1 megohm resistor. V8A will begin to conduct after the capacitor voltage has reached cutoff for the tube. The reset relay will operate when tube conduction current becomes sufficient. The time necessary for this to occur is dependent upon the initial charge on the capacitor which in turn is determined by the setting of the potentiometer, R24. Operation of the relay resets the control circuit for the next cycle of operation.

Another set of contacts on the control relay serve to operate the film-advance relay, CR3, in the plate circuit of V8B. This tube is normally not conducting due to fixed bias placed on the cathode from a voltage divider consisting of resistor R30 and potentiometer R31. Capacitor C9 is initially charged to this same voltage. Operation of the control relay places this capacitor in series with R28 and R29. At this instant, the grid to cathode voltage is essentially zero volts, the tube will conduct and relay CR3 will be energized. Contacts on this relay close to complete the circuit to the camera solenoid. However, as the capacitor discharges, the grid will go negative with respect to cathode and the tube current will decrease to a value insufficient to operate CR3. The time required for this to occur may be varied by adjustment of R29. It is necessary that this time be less than the reset time for the trigger circuit so that the film will be positioned correctly before the next sferic is to be photographed.

The output of the Eccles-Jordan trigger circuit is also fed to the grid of a 6AK5 cathode follower amplifier, V9. The output of this amplifier is differentiated by the action of C12, R32 and R33 and fed to the trigger output jack of this unit through one half of a 6AL5, V10, so that only the positive going portion is passed on to the oscilloscope gating and timing unit. The leading edge of this signal occurs simultaneously with the leading edge of the Eccles-Jordan circuit output.

Oscilloscope Gating and Timing Unit[10]

Most of the modifications which were necessary to obtain data at longer sweep durations were made in the oscilloscope gating and timing unit. The schematic diagram given in Figure 6 shows the circuits after all modifications were made.

The trigger pulse derived from the photographic synchronizer is applied to a very short time constant differentiating circuit. The positive "spike" produced is used to trigger a one-shot multivibrator, V5. The multivibrator output is a rectangular pulse used for unblanking the oscilloscope for a specific time interval while the sferic signal is being displayed. The duration of this pulse is determined by the charging time constant for the capacitor C15. This duration may be adjusted to any value from about 50 microseconds to 5000 microseconds by means of the potentiometer R21. The end of this pulse occurs when the capacitor has charged to the point where

[10]Herbert L. Jones, Research on Tornado Identification, Third Quarterly Progress Report, File Number 11587-PH-91, Signal Corps Research, pp. 11-17.

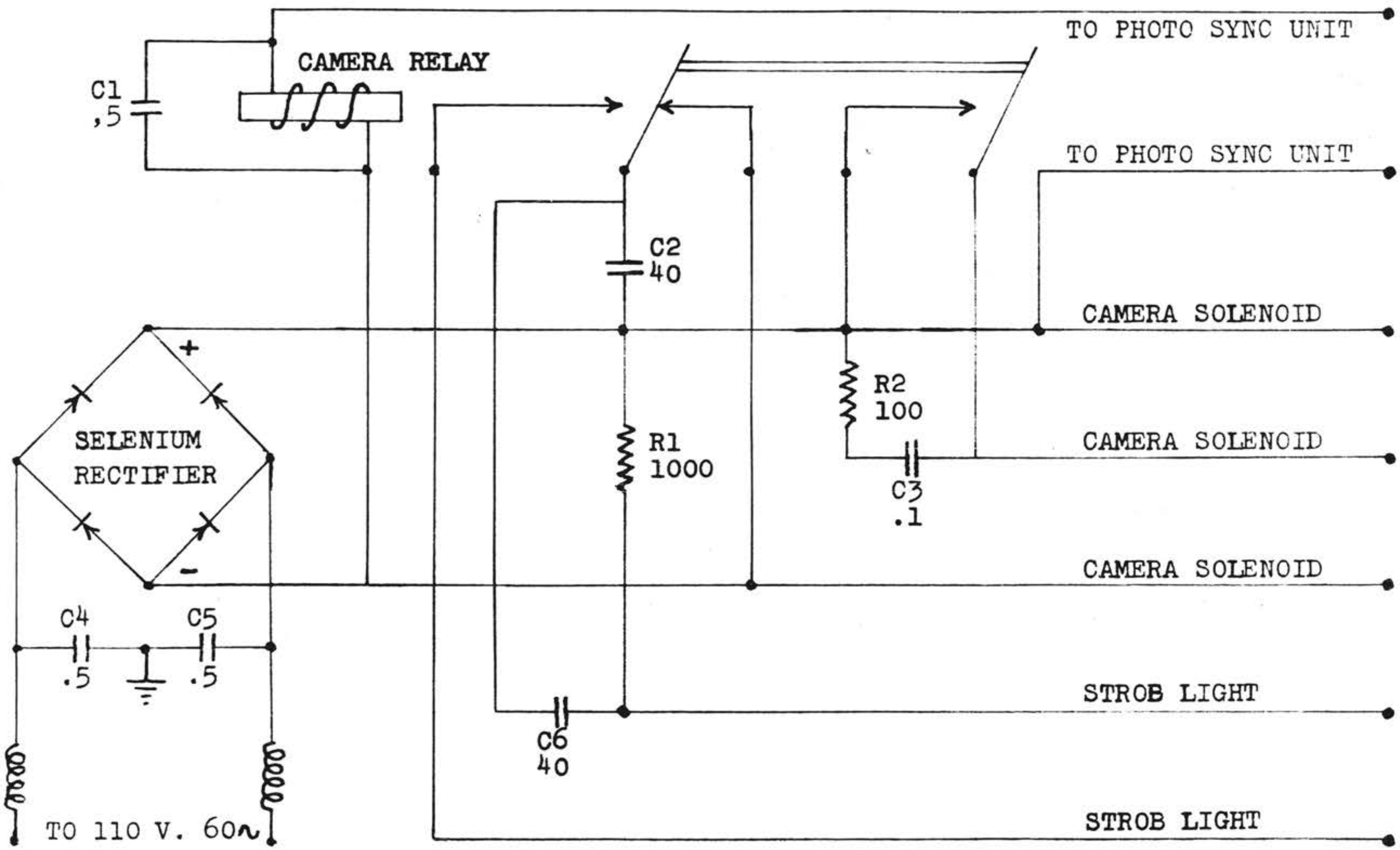

FIGURE 6. CAMERA RELAY UNIT, SCHEMATIC DIAGRAM

the grid voltage of V5B will permit the tube to conduct once more. Originally, a 6SN7 tube was used in this circuit. However, to obtain the longer sweep duration, it was necessary to replace this tube with a 6SL7 which has a cut-off voltage which is much less negative than the 6SN7, thus allowing the capacitor to charge for a longer period of time before V5B starts to conduct. The output of the multivibrator is fed to a 6J5 amplifier, V6, and then to the grid of V4B, one half of a 6SN7. A potentiometer in the cathode circuit of this tube permits adjustment of the amplitude of the unblanking pulse or gate. Negative timing markers are applied to the plate of amplifier V4B, hence the output consists of a positive gating pulse which is serrated by the negative timing markers. This composite signal is fed to a two-tube cathode follower similar in design to that used in the antenna cathode follower circuit and the amplifier preceding the DuMont 241 amplifier. The output of the cathode follower is applied directly to the Z axis input of the DuMont 304-H oscilloscope. The additional amplifier previously employed for inverting the signal is not necessary since the DuMont 304-H scope requires a positive unblanking voltage. The timing markers serve to blank the scope trace at accurate time intervals so that necessary measurement on the sferic waveforms can be made. This gating pulse is also applied to the direction finding scope so that unblanking of this scope occurs simultaneously with unblanking of the wave shape scope.

The timing markers are derived from a 100 kilocycle per second crystal controlled oscillator circuit, V1. A blocking oscillator count-down circuit is employed to obtain the desired marker spacings, V2. Three different spacings may be selected by means of a switch on the front panel of the unit, 20 microseconds, 50 microseconds and 200 microseconds. The 200 microsecond markers replace the 10 microsecond markers in the original unit. Two hundred microsecond markers are necessary for studies involving longer sweep durations. The output of the count-down circuit, tube V2B, is a sawtooth signal which when differentiated will produce negative "spikes" with the proper time spacing. The time constant of the differentiating circuit determines the width of the markers. It was necessary to make a provision for altering this width for the different marker spacings since narrow pulses which were satisfactory for shorter sweeps were not visible when longer sweeps and more widely spaced markers were used. The second half, S1B, of the same switch which controls the marker spacing, S1A, is used to vary the time constant of the discharge circuit for capacitor C11. The markers thus produced are fed through two amplifiers, V3 and V4A. A potentiometer in the cathode of V4A permits adjustment of their amplitude. The plate of V4A is tied directly to the plate of V4B where the markers are mixed with the gating pulse.

Camera Control Circuit

The camera is a modified 35 mm. movie camera driven by a rotary sólenoid which advances the film one frame after exposure by a single incoming sferic waveform. The camera has no shutter so the film is exposed immediately as soon as the wave shape is displayed on the oscilloscope. Operation of the solenoid is controlled by the film-advance relay in the photographic synchronizer unit. The camera control circuit is given in Figure 7.[11] It should be noted that this circuit also controls a strob light for illuminating a clock and date card so that this information is included on each frame. Additional information such as marker spacing, etc., may be placed on the date card. A selenium bridge rectifier is used to supply the d-c voltage to operate the camera. Voltage will be applied to the camera and strob light when the terminals marked "To Photo Sync Unit" are shorted together by the film-advance relay. Since the camera is shutterless, the direction finding scope, wave shape scope, clock and camera must be installed in a light tight box to prevent pre-exposure of the film which is in place ready for exposure at all times.

Summary

The equipment as described in this chapter provides a satisfactory means for obtaining information concerning the characteristics of the sferic waveform for a time duration from 50 microseconds to 5000 microseconds after the initial surge of current in the lightning stroke. Additional infor-

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[11] Odell, A Study of Tornado Tracking Equipment, pp. 18-21.

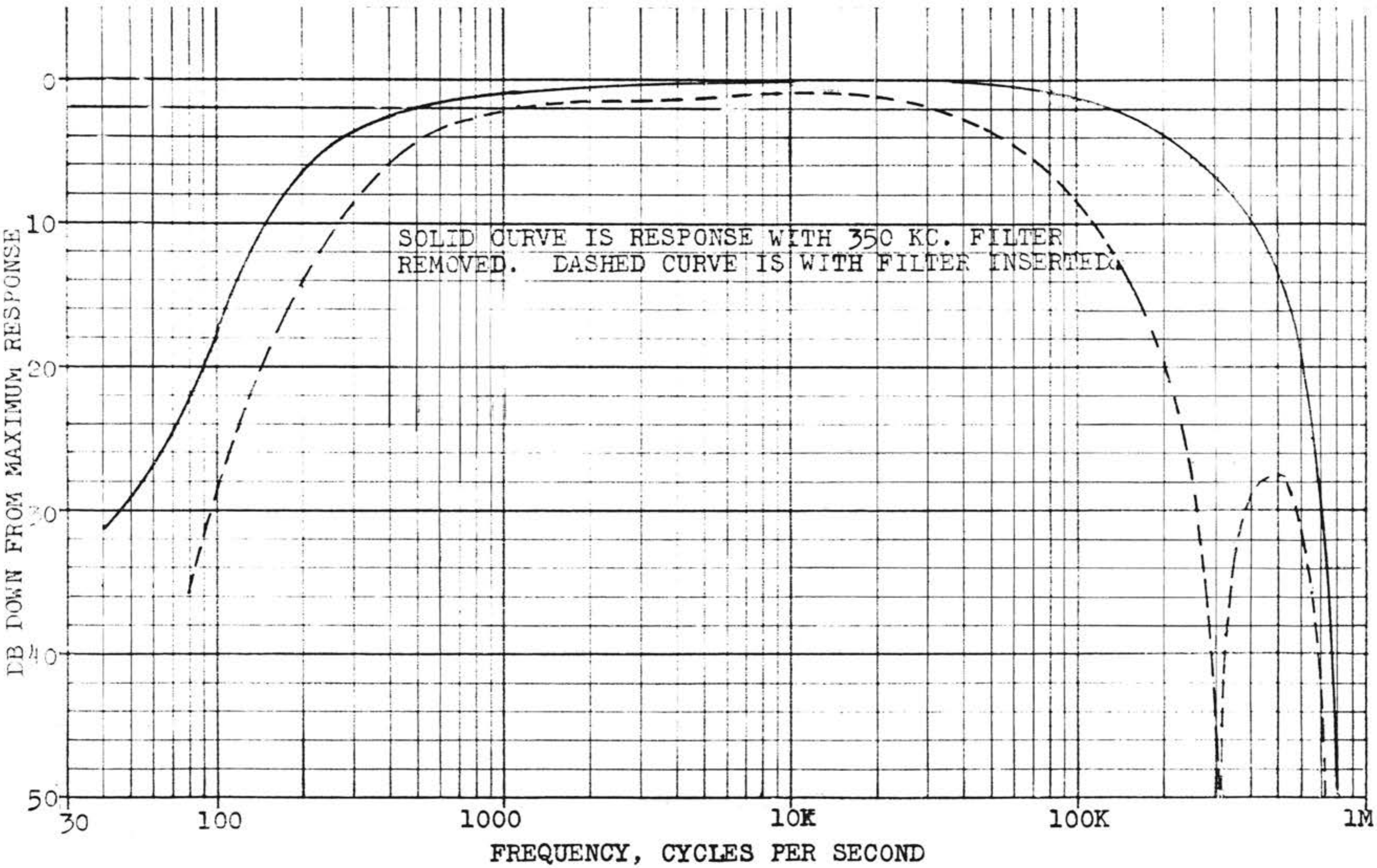


FIGURE 7. OVERALL FREQUENCY RESPONSE

mation as to the direction of the stroke and its time of occurrence is obtained with a permanent photographic record. Experimental data taken with this equipment is presented in following chapters.

CHAPTER IV

EXPERIMENTAL OBSERVATIONS

Direction finding equipment was installed at the Oklahoma City Laboratory in April of 1952. Temporary equipment for visual observation of the sferic wave shape was constructed and placed in operation a short time later. During the spring and summer, several thunderstorms were observed. No permanent data were taken during this period however since photographic equipment was not available. Communication with the Stillwater laboratory was not possible at this time for correlation of direction finder indications. The major objectives which were accomplished were (1) study of existing literature to obtain a better understanding of the overall problem, and (2) becoming familiar with the operation of the direction finding equipment. It was also necessary to devote appreciable time to securing the facilities necessary for the laboratory, e.g. electric power, tools, component parts, test equipment, etc.

The sferic waveform equipment, including photographic equipment, was installed in early spring of 1953. Necessary modifications to permit gathering of data using oscilloscope sweep durations up to 5000 microseconds were made and the complete equipment was placed in operation in May. A plotting board was constructed to aid in following the progress of the storm cells. The experimental data described in the following paragraphs were taken during the month of June, 1953. Over 400 feet of film was used in obtaining data during this period. An appreciable portion of this film was devoted to sweep durations of 2000 microseconds or greater since these were of primary interest in this study. Representative photographs taken using a 4000 microsecond trace are included at the end of this chapter. It should be noted here that the direction finding equipment is oriented with respect to magnetic north with north being at the top of the scope tube and east to the right.

A general summary of experimental observations is given in chronological order in the following sections. A complete, detailed analysis of the photographic data is being made by Mr. J. P. Lindsey at the present time and will be included in his thesis at a later date. In some cases the photographic record is not completely satisfactory, however, as much information was obtained from this film as possible. Only the longest sweep was used in determining the sferic duration distribution for any particular storm, and shorter sweeps were studied to determine whether high frequency components were present.

June 2, 1953

The first attempt to obtain photographic data was made on the night of June 2, 1953 between 9:00 and 10:00 p.m. Sferics were received from a northerly direction, limited to a segment between 20° west of north to 10° east of north. Conditions in the vicinity of Oklahoma City were clear. Triangulation measurements made after obtaining information from the Stillwater laboratory indicated that the storm was at an appreciable distance from the stations. On the following day this was verified when weather reports showed that the only thunderstorm activity had been in Nebraska where some tornado activity was reported. No high frequency components are present in the sferic waveforms obtained. This is to be expected due to the great distance from the storm activity. Approximately 10% of the sferics recorded lasted for 2000 microseconds or over, with the majority of them being between 500 to 1000 microseconds.

June 4, 1953

From 12:00 Noon until 1:00 p.m. on June 4, 1953 photographic data were taken. Sferics were received from two major directions, along a NE-SW line and a NW-SE line. This activity was apparently arriving from a squall line which had started to develop in western Oklahoma. Practically all of these sferics lasted for durations between 200 and 700 microseconds. No high frequency components were noted.

At approximately 10:00 P.M. on the evening of June 4, information was received from the Stillwater laboratory that radar precipitation echoes were observed near Taloga, Oklahoma and west of Cherokee, Oklahoma. The photographic record obtained from this activity is not sufficiently readable to give usable data.

June 5, 1953

The squall line which formed in Western Oklahoma moved eastward across the state. Storms which occurred on this date were quite severe, with reports of tornadoes from at least five different locations. It was necessary to perform some work on the equipment, and as a result, no photographic data were taken until 3:25 p.m. The data gathered between 3:25 and 3:45 p.m. shows an increase in the high frequency components as compared to previous storms. At this time the squall line was quite near since it passed over Oklahoma City at 5:30 p.m. Unfortunately, direction finder indications are not visible on the photographs. The majority of the sferics lasted for a duration of 1000 microseconds or less, however about 10% lasted for 200 microseconds or over.

Photographic data were taken again from 8:04 to 8:45 p.m. Direction finder indications are not visible on this portion of the record. Over 70% of the sferics recorded definitely contain high frequency components as observed on a 200 microsecond sweep. The rate of occurrence during this period was quite high.

June 6, 1953 - June 10, 1953

Short recordings were made on the afternoons of each of these days between 4:35 and 4:37 p.m., and 5:00 and 5:06 p.m., respectively. The data obtained are not usable.

June 18, 1953

The photographic record taken between 4:20 p.m. and 4:25 p.m. and another between 9:25 p.m. and 9:35 p.m. on June 18, shows a number of sferics received from the west, west-south-west, and northwest. Usable information cannot be obtained from the photographs of the wave shape scope. It should be mentioned that the reason for much of this film not yielding usable data is that the negative portion of the waveforms was cut off because of the positioning of the oscilloscope with respect to the camera. This difficulty was not apparent until after the film was developed and as a result corrective action could not be taken until June 26, 1953. Fortunately, much information could still be obtained from an appreciable portion of the film which has been used before this date.

June 19, 1953

Two small squall lines passed over the state on this date. Photographic data was taken both in the afternoon and evening. No high frequency components were noted on either of these records. The duration of sferics follows the same pattern as that shown in previous storms.

June 22, 1953

At 3:30 p.m. on June 22, the Stillwater laboratory advised that a squall line was beginning to form extending from Anthony, Kansas to Fort Sill, Oklahoma. Observations made between 4:43 p.m. and 4:49 p.m. showed that no high frequency components were being received. Practically all signals were coming from the southwest, and activity at this time was at a low level. Additional photographic data were taken between 8:20 and 9:40 p.m. The record is not completely satisfactory, however, it can be seen that a large number of the sferics last for over 4000 microseconds, with frequency components somewhat higher than normal, but not sufficiently so to indicate severe activity. No tornadoes were reported during this time.

June 24, 1953

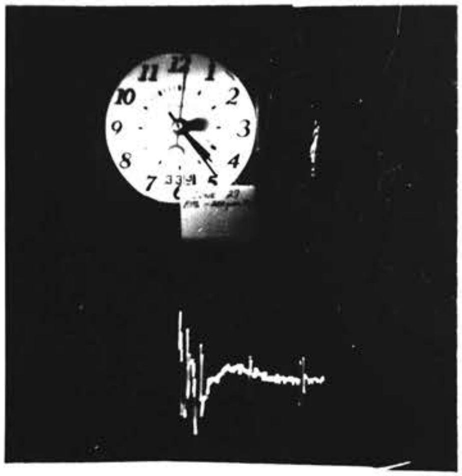
Data taken between 12:50 and 1:10 p.m. on June 24, shows 85% of all sferics originating from a direction 20° west of north. Seventy per cent of these last for a duration of from 400 to 1000 microseconds, with about 10% over 2000 microseconds. No high frequency components are apparent.

At 6:00 p.m. on this date, a squall line extended from Garden City, Kansas to Lubbock, Texas. Observations made on this activity as it moved eastward showed a definite increase in the sferic duration, many of them lasting for longer than 4000 microseconds.

June 27, 1953

The photographic records taken on this date are very satisfactory. Prints of four of the sferics observed are shown in Figure 8 to demonstrate the appearance of the longer sweep durations.

Sferics recorded in the afternoon, between 4:19 and 4:36 p.m. were received primarily from two directions, north and northeast. A definite increase in the number of sferics which last for durations between 1000 and 2000 microseconds is apparent from the photographs taken on a 4600 microsecond sweep. Over 85% of the waveforms have durations of 2000 microseconds or less. Approximately 10% of the sferics received from the northeast direction lasted for over 4600 microseconds, while less than 5% of those from the north direction lasted for over 4600 microseconds.



(a)

(b)

(c)

(d)

FIGURE 8. REPRESENTATIVE PHOTOGRAPHS OF SFERIC WAVEFORMS PRESENTED ON A 4000 MICRO-SECOND SWEEP

No high frequency components could be observed on this sweep duration. A very interesting observation is that the major frequency component of a very large number of these signals is very low, between 2000 and 4000 cps. Several waveforms indicate a basic frequency component of less than 1000 cps.

Photographic data were taken again between 11:30 p.m. and midnight. Radar precipitation echoes were reported by the Stillwater laboratory in the vicinity of Medicine Lodge, Kansas and near Bartlesville, Oklahoma. The sferics received from a direction of 20° west of north are quite interesting. Practically all of them had durations in the range of from 1800 to 3600 microseconds, with over 50% of them lasting from 2400 to 3200 microseconds. Over 15% of these sferics had a duration of over 4200 microseconds. A small number of sferics with frequency components somewhat higher than normal were noted.

Sferics received from the northeast showed a distribution of durations more similar to that previously observed, most being in the range between 800 and 1200 microseconds.

Four of the sferic waveforms taken on this data are shown in Figure 8 to illustrate some of the aspects of observations made on a sweep duration of approximately 4000 microseconds. In particular, the following characteristics should be noted:

Figure 8(a): The appearance of multiple strokes on a single sweep permits measurement of the time interval between strokes. Verification that strokes come from the same direction can be made by reading the direction finder. In some cases two or more distinct directions may be noted and in other cases only a single direction is noted for two or three sferics on the same trace.

Figure 8(b): This photograph shows a very low frequency sferic which lasted for a duration of over 4000 microseconds.

Figure 8(c): A somewhat higher frequency sferic which decreases to a small amplitude in less than one-half the trace duration, but continues at this lower level for the remainder of the trace is illustrated here.

Figure 8(c): This illustrates a high amplitude low frequency sferic followed by a higher frequency but low amplitude signal.

CHAPTER V

SUMMARY AND CONCLUSIONS

At the present time, the quantity of data available is not sufficient to arrive at any definite conclusions concerning the correlation of the duration of sferic waveforms with a particular meteorological condition. However, it is apparent that a very wide variation in durations exists, and additional research to establish a definite correlation would be very worthwhile. A particularly important investigation which should be made involves the relationship of the duration of the sferic to the frequency components, with emphasis on the duration of the high frequency sferics associated with tornadoes. It appears quite possible that such sferics consist of a high frequency superimposed upon a low frequency variation of long duration. It is difficult to obtain data to ascertain the presence of high frequency sferics when observations are made on a 4000 microsecond trace. It is therefore suggested that an investigation using two separate cathode-ray tubes, one having a 4000 microsecond trace and the other having a 100 or 200 microsecond trace, might be of value. By displaying the sferic on these two traces simultaneously and obtaining a photograph of the two together, definite correlation could be established if such exists.

In general, the equipment proved to be quite satisfactory after the modifications were completed as described in the preceding material. The addition of radar equipment at satellite stations would be very advantageous. To obtain more accurate direction finding information, the present equipment should be modified by replacing the two-inch cathode-ray tube with a five-inch tube and placing an illuminated angular scale around its periphery. If this scale were constructed of lucite, it could be lighted from the edge and the illumination synchronized with the camera operation.

After the complete analysis of the data taken at the Oklahoma City laboratory has been completed by Mr. J. P. Lindsey, additional information will undoubtedly be made available in his thesis for those continuing this study. It is recommended that further investigations of the duration of the sferic waveforms be conducted.

BIBLIOGRAPHY

Associated Press. "249 Twisters Hit This Year; Record is Seen." Oklahoma City Times, LXIV (June 10, 1953), 9.

Bless, A. A. Propagation and Reception of Sferics. (Summary and Bibliography). Gainesville, Florida; Engineering and Industrial Experiment Station, University of Florida, ----.

Cruft Electronics Staff. Electronic Circuits and Tubes. New York: McGraw-Hill Book Co., 1947.

Donn, William L. Meteorology with Marine Applications. New York: McGraw-Hill Book Co., 1946.

----. "Du Mont Cathode-ray Oscillograph Type 241." Operating and Maintenance Manual. Instrument Division, Allen B. Du Mont Laboratories, Clifton, New Jersey, ----.

----. "Du Mont Cathode-ray Oscillograph Types 304 and 304-H." Operating and Maintenance Manual. Instrument Division, Allen B. Du Mont Laboratories, Clifton, New Jersey, ----.

Federal Telephone and Radio Corp. Reference Data for Radio Engineers. New York: Federal Telephone and Radio Corp., 1949.

Hammack, Calvin M. "Cathode Follower of Very Low Output Resistance." Electronics, 19 (November, 1946), 206-210.

Harrison, L. P. Lightning Discharges to Aircraft and Associated Meteorological Conditions. (Technical Note No. 1001) Washington, D. C.: National Advisory Committee for Aeronautics, 1946.

Hess, Philip N. "Installation and Operation of Electronic Sferic Detection Equipment." Unpublished Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1950.

Hill, James C. "Sferic Waveform Identification of Destructive Windstorms and Tornadoes." Unpublished Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1951.

Holzberlein, Thomas M. "A Study of Tornado Tracking Equipment." Unpublished Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1951.

Jones, Herbert L. and Philip N. Hess. "Identification of Tornadoes by Observation of Waveform Atmospherics." Proceedings of the I.R.E., 40 (September, 1952), 1049-1052.

Jones, Herbert L. "Research on Tornado Identification." First Quarterly Progress Report, File Number 11587-PH-52-91, Signal Corps Research, 1952.

Jones, Herbert L. "Research on Tornado Identification." Second Quarterly Progress Report, File Number 11587-PH-52-91, Signal Corps Research, 1952.

Jones, Herbert L. "Research on Tornado Identification." Third Quarterly Progress Report, File Number 11587-PH-52-91, Signal Corps Research, 1952.

Jones, Herbert L. "Research on Tornado Identification." Fourth Quarterly Progress Report, File Number 11587-PH-52-91, Signal Corps Research, 1953.

Jones, Herbert L. "Research on Tornado Identification." Fifth Quarterly Progress Report, File Number 11587-PH-52-91, Signal Corps Research, 1953.

Jones, Herbert L. A Sferic Method of Tornado Tracking and Identification. Stillwater, Oklahoma: Oklahoma Engineering Experiment Station, Oklahoma Agricultural and Mechanical College, 1952.

Kessler, William J. Direction Finding and Ranging on Atmospherics. (Final Report on U. S. Army Signal Corps Laboratories Contract No. W28-003-sc-1306). Gainesville, Florida: Engineering and Industrial Experiment Station, University of Florida, 1948.

Kessler, William J. Direction Finding and Ranging on Atmospherics. (Quarterly Progress Report No. 1 on U. S. Army Signal Corps Engineering Laboratories Contract No. W36-039-sc-38201). Gainesville, Florida: Engineering and Industrial Experiment Station, University of Florida, 1949.

Odell, Albert C. "A Study of Tornado Research Equipment." Unpublished Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1953.

----. Static Direction Finder AN/GRD-1A. War Department Technical Manual TM 11-2693. Washington, D. C.: United States War Department, 1945.

Wade, Vernon D. "Development and Operation of a Crossed Loop Sferic Direction Finder." Unpublished Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1951.

Wagner, C. F. and G. D. McCann. "Lightning Phenomena." Electrical Transmission and Distribution Reference Book. (Chapter 12). East Pittsburgh, Pennsylvania: Westinghouse Electric and Manufacturing Co., 1944.

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